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EVALUATION OF A CONCRETE TEST HAMMER

D. R. Williams

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SUMMARY

A non-destructive concrete tester, developed by the Swiss engineer, Ernst Schmidt, was evaluated by the U. S. Naval Civil Engineering Research and Evaluation Laboratory to determine its adequacy for obtaining the approximate compressive strength of concrete *in situ*.

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INTRODUCTION

The Bureau of Yards and Docks purchased a Concrete Test Hammer for evaluation by the Laboratory and for possible field use. The Structures Research Department was authorized by the Officer in Charge, U. S. Naval Civil Engineering Research and Evaluation Laboratory, to test this device by comparing the readings obtained from it with the compressive strengths of concrete found with accurate laboratory testing machines.

This instrument is claimed by the manufacturer to be useful in the field for obtaining rapid determinations of the approximate compressive strengths of concrete.

DESCRIPTION

The instrument (Figs. 1 and 2), referred to as the Concrete Test Hammer, consists of a light-weight steel hammer, or plunger, free to travel in a tubular frame. By means of a trigger, the hammer is drawn upward against the force of two tension springs. With the base held firmly against the concrete and with the springs fully extended in the cocked position, the trigger is released allowing the extended springs to drive the hammer against the concrete. The height of the first rebound of the hammer is measured by a small sliding pointer which slides over a calibrated scale. This scale is approximately 5 inches long graduated from 0 to 100, each unit a division and approximately 0.05-in. apart. The amount of this rebound (R) is an indication of the hardness of the concrete at the point of impact and is, therefore, purported to be a measure of the compressive strength.

PREPARATION OF CONCRETE SPECIMENS

Six- by twelve-inch concrete cylinders, 1,188 in number, fabricated for use in other studies, were utilized to establish the relationship between the rebound number (R) and the compressive strength. These specimens consisted of concrete made with Colton Type I portland cement and with aggregates from four different sources. Three cement contents--3.5, 5.5, and 7.5 sacks per cubic yard of concrete--were used with each aggregate. Slumps of 1, $3\frac{1}{2}$, and 6 inches were attained with each cement content. In addition, under carefully controlled laboratory conditions, different combinations of curing and storage (100% R.H. at 73°F , and 50% R.H. at 73°F) were employed for specimens tested at age 7, 28, and 90 days. The compressive strength of the specimens ranged from 800 to 7000 psi.

The dense aggregates which were used in these concretes are particularly representative of aggregates found along the west coast of the United States and their composition ranges from hard tough durable rocks to rocks that are chiefly sandstones. Petrographic analysis and physical properties of the aggregates appear in Appendix I.

TEST METHOD

As recommended by the manufacturer, the following procedure was employed to determine the correct rebound number:

1. The bottom of the specimen, having been cast in a machined mold, was smooth and uniform and was, therefore, selected for the test location. Rough spots, honeycombs, and porous areas were avoided.
2. Readings were taken at six to ten points on the selected area. After each impact, the hammer was moved to avoid more than one impact at a given point. The exact number of determinations depended upon the variation of the readings obtained. Not more than one-third of the readings were permitted to deviate more than three scale divisions from the average. The average was then selected as the rebound number for that particular specimen.

The ends of the concrete cylinders were then capped with an approved proprietary sulphur and fire clay capping compound and the specimens tested in compression in a 300,000 lb capacity Riehle Testing Machine.

Using the above method, rebound determinations were made on approximately 850 specimens. At that time, the coefficient of friction of the hammer in the tube exceeded that recommended by the manufacturer. The original instrument was replaced with a new one for the remainder of the evaluation; this was done in lieu of repairing or adjusting the first instrument.

RESULTS

Figures 3, 4, 5, and 6 show average curves of compressive strengths vs rebound number for concretes made from each of the four aggregates. Each point on the curve represents one 6- by 12-in. concrete cylinder. These curves represent all specimens of each aggregate regardless of age, cement content, or curing condition.

Experience in the measurement of properties of a given material (such as carefully controlled concrete) has shown that the results of

tests will group more or less symmetrically around the average value in such a manner that a large number vary but little from the average, a lesser number vary more widely, and a few show large differences. This grouping of the individual tests results in relation to the average can be expressed in terms of the variations from the average by a single numerical value known as "standard deviation". "Standard deviation" (SD) is the square root of the average of the squares of the deviations of the individual test results from their average. $SD = (\sum d^2/n)^{1/2}$ where d is the deviation of the strength of an individual cylinder from the average and n is the number of specimens.

The standard deviation of strength from the averages shown in Figures 3, 4, 5, and 6 was computed for each rebound number. Curves indicating the average of these standard deviations are also shown on those figures.

The following table indicates the range in strength within the limits of plus and minus one standard deviation which similarly must be expected to occur with additional cylinders fabricated with the indicated aggregates, cured and tested under the same carefully controlled conditions; the values are based on the curves in Figures 3, 4, 5, and 6.

| REBOUND NUMBER | R = 30 | | | R = 40 | | | R = 50 | | |
|----------------------|----------------------------|--|----------------------------|--|----------------------------|--|--------|--|--|
| | Average Strength psi | Strength Range From -One SD to +One SD psi | Average Strength psi | Strength Range From -One SD to +One SD psi | Average Strength psi | Strength Range From -One SD to +One SD psi | | | |
| Santa Clara River | 2400 | 1700-3100 | 4350 | 3500-5200 | 6250 | 5450-7050 | | | |
| Winn Pit | 2550 | 1900-3300 | 5650 | 4400-6900 | 7400 | 6300-8500 | | | |
| San Gabriel River | 2650 | 2000-3300 | 4350 | 3600-5200 | 6200 | 5400-7000 | | | |
| Feather River | 2450 | 1600-3220 | 4670 | 3710-5630 | 6360 | 5450-7270 | | | |

To determine the effect that curing and storage conditions may have upon strength vs rebound curves, Figures 7 through 14 were constructed using data obtained only from concrete made of San Gabriel River aggregate. These curves represent various combinations of wet curing and dry storage conditions, and different ages of test. Each point plotted represents one specimen.

Upon examination of Figures 7, 8, 9, and 10, it may be seen that the curves have nearly the same shape and slope for concretes at 90 days of age if the specimens were stored under drying conditions (73°F and 50% R.H.) for at least 62 days and regardless of whether they had been previously fog-cured (73°F and 100% R.H.) for periods of 3, 7, 14, or 28 days; it is to be noted that these particular data are for one aggregate only and are not summary curves for all the aggregates.

Upon examination of Figures 11, 12, and 13 it may be seen that curves for specimens that were fog-cured until the time of test are also nearly coincidental even though they were tested at age 7, 28, and 90 days, respectively. It is to be noted that this set of curves differ considerably in slope with the set which represents specimens that were permitted to dry out for at least 62 days. This fact may be seen clearly in Figure 14 which contains two curves each of which represents specimens which were tested at age 90 days; one represents fog-cured specimens (same as Fig. 13) and the other, a combination of specimens that were permitted to dry out (same as Figs. 8 and 9).

In order to show the effect of aggregate on these data, a comparison of the 7-day test data may be made using the curves in Figures 15, 16, 17, and 18. These curves represent specimens having identical curing conditions and test age; the only variable is the aggregate. The curves agree fairly well, one with the other and have the same general slope, but it must be remembered that all of these specimens were tested at the early age of seven days.

DISCUSSION

Surface Hardness

Since the hammer rebounds from the surface, the amount of rebound is influenced by the hardness of the concrete surface. It has been shown by others¹ that the surface hardness of concrete (and thus the applicability of the concrete test hammer) is dependent upon various factors including: concrete fabrication process used, age of the concrete, humidity conditions during and after curing, per cent of fine material, and the size of the aggregate near the surface. It would appear that all except the last of these five factors

mentioned have direct bearing on the quality of the paste in the concrete.

It is common knowledge that the following greatly influence the compressive strength of concrete: quality of the paste, workability of the concrete, adequacy of compaction, and the quality of the aggregate. Of these, only the quality of the paste appears as a common factor with those previously listed as having a large influence on surface hardness. Therefore, it is unfortunate that a concrete of a harsh mix or improper compaction may produce identically the same rebound number as a sound, well compacted concrete with a similar comparable surface hardness; however, because of internal honeycombs, the compressive strength of the harsh mix will be much less than that of the sound concrete.

Smooth trowelled surfaces appear to give higher rebound readings than do rough floated surfaces, the compressive strengths of the concretes being the same. Similarly, small air pockets under the surface result in lower readings than do impacts immediately over a piece of aggregate.

Reliability of Data

The analysis of data given in this paper is based primarily on the use of standard deviation as was previously defined on page 3. Under the observed carefully controlled conditions of fabrication, curing and testing, the concrete cylinders in this program would be expected to yield compressive strengths, for any given rebound number, having a normal distribution about an average value. With such a distribution, approximately two-thirds of all the values obtained in any instance would lie in the range of plus and minus one standard deviation. Actually, instead of two-thirds, the figure given in the ASTM Manual on Presentation of Data, is 68.27 per cent.

From the foregoing then, and relating it to the data in the table on page 3, it may be seen that if a rebound number of 40 was obtained from concrete consisting of Santa Clara aggregate, the strength would be expected to be between 3500 and 5200 psi only about two-thirds (68.27%) of the time. Such a range is equivalent to 50 per cent of the lower value, 33 per cent of the higher, and plus or minus almost 20 per cent over the average value of 4350 psi. Furthermore, it must be again noted that about one-third of all the values will lie outside of even this wide range.

Field conditions encountered in the fabrication, curing, and testing of concrete cylinders, miscellaneous specimens, monolithically

poured columns, walls, and other elements, could scarcely be relied upon to give data having a normal distribution of values as conservative as those observed in this program. It would, therefore, be expected that the range of even plus or minus one standard deviation would be comparatively greater for job-site concretes than that shown herein.

To obtain realistic curves for concretes of one aggregate, cured under specific conditions and tested at reasonably the same age, it may be necessary to make and test 50 to 100 specimens. This number should be increased proportionately as the number of variables increase and as the amount of control decreases.

Reference 2 indicates that the calibration curve supplied by the manufacturer is based on 550 specimens which were made with "aggregates approved for construction work". About 90 per cent of those specimens were prepared at various job locations and shipped to a laboratory for compressive strength tests and hammer readings.

Hammer Position

For the purpose of this investigation all tests were made with the instrument in a vertical position; with the hammer in any other position the effect of hammer friction would necessitate the use of a correction factor which is supplied by the manufacturer; this factor was not checked by the Laboratory.

CONCLUSIONS

1. There appears (for all dense aggregate concretes) to be an approximate empirical relationship between surface hardness as measured by the hammer rebound, and the compressive strength of concrete, within the limits of 800 and 7000 psi.

2. Concrete specimens from the same aggregate source, tested at the same age, and having nearly the same curing and storage conditions will produce good correlation between rebound numbers and compressive strength.

3. When many variables are considered, it would be erroneous to use the curve which was supplied with the instrument (or any one modification of the curve) to predict the compressive strength of all concretes.

4. The Test Hammer may have use for any one concrete, made of certain aggregates, cured under specific conditions, tested at

reasonably the same age, and for which correlative test data may be plotted to obtain a realistic curve. Such an instance may be found in a job where a large quantity of concrete is to be used, and all of it is of one type with a minimum strength requirement.

5. Extensive use may be made of the Concrete Test Hammer for estimating the compressive strength of concrete for operations such as removal of shoring. This may be accomplished by selecting from predetermined data the highest rebound number for the minimum required compressive strength. It should be noted, however, that this practice may invoke a severe penalty on performance in that the compressive strength may be considerably in excess of that required.

REFERENCES

1. Hoeffgen, H., and G. Back, "Erfahrungen über die Zerstörungsfreie Betonprüfung mit Kugelprüfgeräten" (Comparison of Methods of Non-destructive Testing of Concrete with Ball-Testing Instruments), Bauingenieur, Vol. 26, No. 10, October 1951, pp 297-300 incl.
2. Schmidt, E., "A Non-destructive Concrete Tester", Concrete, Vol. 59, August 1951, p 34.

COARSE AGGREGATE

Mechanical Analysis and Physical Properties

TABLE I

| Std. Sierr e Size | Santa Clara | | | San Gabriel | | | Feather River | | | Winn Pit | | |
|---|-------------|----------|---------|-------------|----------|---------|---------------|----------|---------|----------|----------|---------|
| | % Ret. | 20% Ret. | 5% Ret. | % Ret. | 20% Ret. | 5% Ret. | % Ret. | 20% Ret. | 5% Ret. | % Ret. | 20% Ret. | 5% Ret. |
| 1 in. | 0 | 0 | 0 | 0 | 0 | 0 | 01 | 01 | 0 | 0 | 0 | 0 |
| 3/4 in. | 01 | 01 | 0 | 0 | 0 | 0 | 02 | 05 | 0 | 0 | 0 | 0 |
| 1/2 in. | 43 | 44 | 50 | 50 | 50 | 30 | 35 | 33 | 26 | | | |
| 3/8 in. | 44 | 28 | 36 | 36 | 36 | 32 | 37 | 35 | 27 | | | |
| "0.4 | 99 | 97 | 10 | 96 | 96 | 23 | 100 | 63 | 99 | | | |
| Pan | 93 | 100 | 64 | 100 | 0 | 100 | 100 | 10 | 100 | | | |
| F.M. | | | | | | | | | | | | |
| Sy. Gr. | 2.53 | | | 2.66 | | 2.39 | | 2.59 | | | | |
| 24-hour Absorb. | | | | | | | | | | | | |
| Los Angeles abrasion, % loss, 100 Ret. | | 6.23 | | | | | 2.48 | | 3.65 | | | |
| Los Angeles abrasion, % loss, 500 Ret. | | | | 33.0 | | | 13.52 | | 18.05 | | | |

"3" grading used in abrasion test.

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Mechanical Analysis and Physical Properties

TABLE 2

| Std. Sieve Size | Source | Santa Clara | | | San Gabriel | | | Feather River | | | Winn Pit | | |
|-----------------------|--------|-------------|---------|--------|-------------|--------|---------|---------------|---------|--------|----------|--------|---------|
| | | % Ret. | Size, % | % Ret. | Size, % | % Ret. | Size, % | % Ret. | Size, % | % Ret. | Size, % | % Ret. | Size, % |
| No. 4 | | 05 | 05 | 03 | 03 | 03 | 03 | 03 | 03 | 03 | 03 | 03 | 03 |
| No. 2 | | 15 | 20 | 15 | 13 | 12 | 15 | 12 | 12 | 12 | 12 | 12 | 12 |
| No. 16 | | 19 | 39 | 16 | 34 | 09 | 24 | 14 | 14 | 14 | 14 | 14 | 14 |
| No. 30 | | 24 | 63 | 23 | 57 | 24 | 48 | 26 | 26 | 26 | 26 | 26 | 26 |
| No. 50 | | 24 | 57 | 26 | 53 | 42 | 90 | 34 | 34 | 34 | 34 | 34 | 34 |
| No. 100 | | 11 | 93 | 14 | 97 | 09 | 99 | 13 | 13 | 13 | 13 | 13 | 13 |
| Pan | | 02 | 100 | 03 | 100 | 01 | 100 | 01 | 100 | 01 | 100 | 01 | 100 |
| F. W. | | 3.12 | - | 2.92 | - | 2.79 | - | 2.74 | - | 2.74 | - | 2.74 | - |
| color | | | | | | | | | | | | | |
| test | | | | | | | | | | | | | |
| Percent silt | | | | | | | | | | | | | |
| content | | | | | | | | | | | | | |
| Specific | | | | | | | | | | | | | |
| gravity | | | | | | | | | | | | | |
| 24-hour | | | | | | | | | | | | | |
| absorp. percent | | | | | | | | | | | | | |

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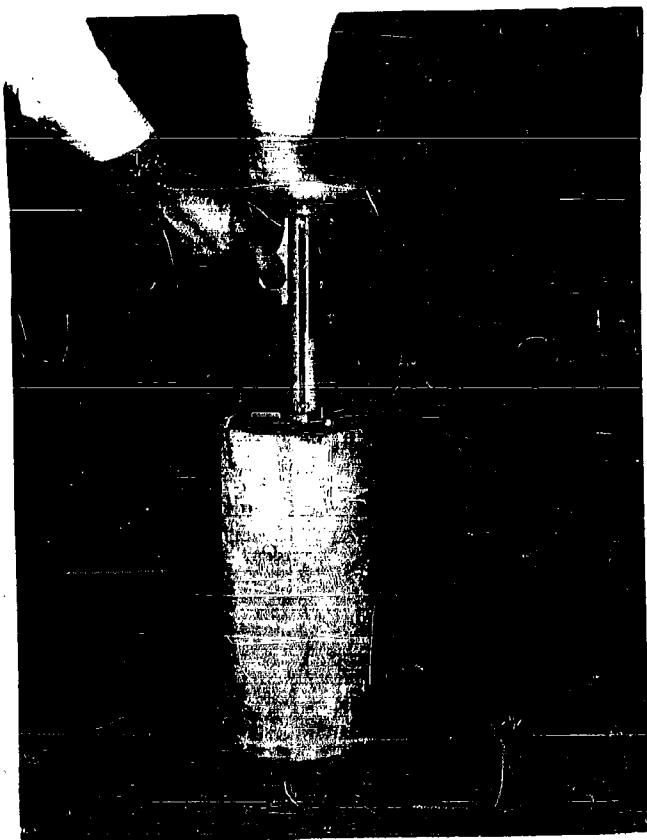
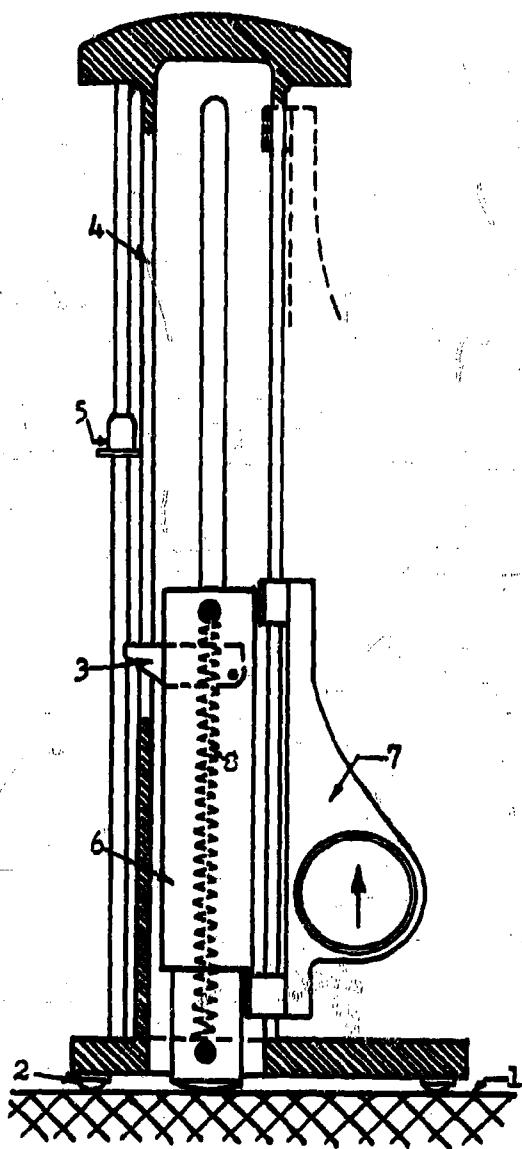


Figure 1. Concrete Test Hammer In Use.

SHARON TATE HALL

OPERATING INSTRUCTIONS FOR CONCRETE TEST HAMMER

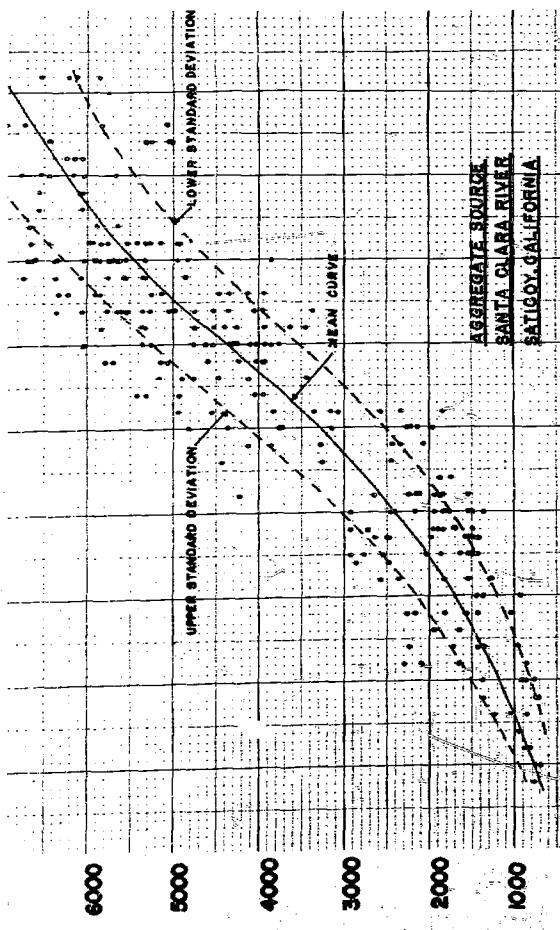
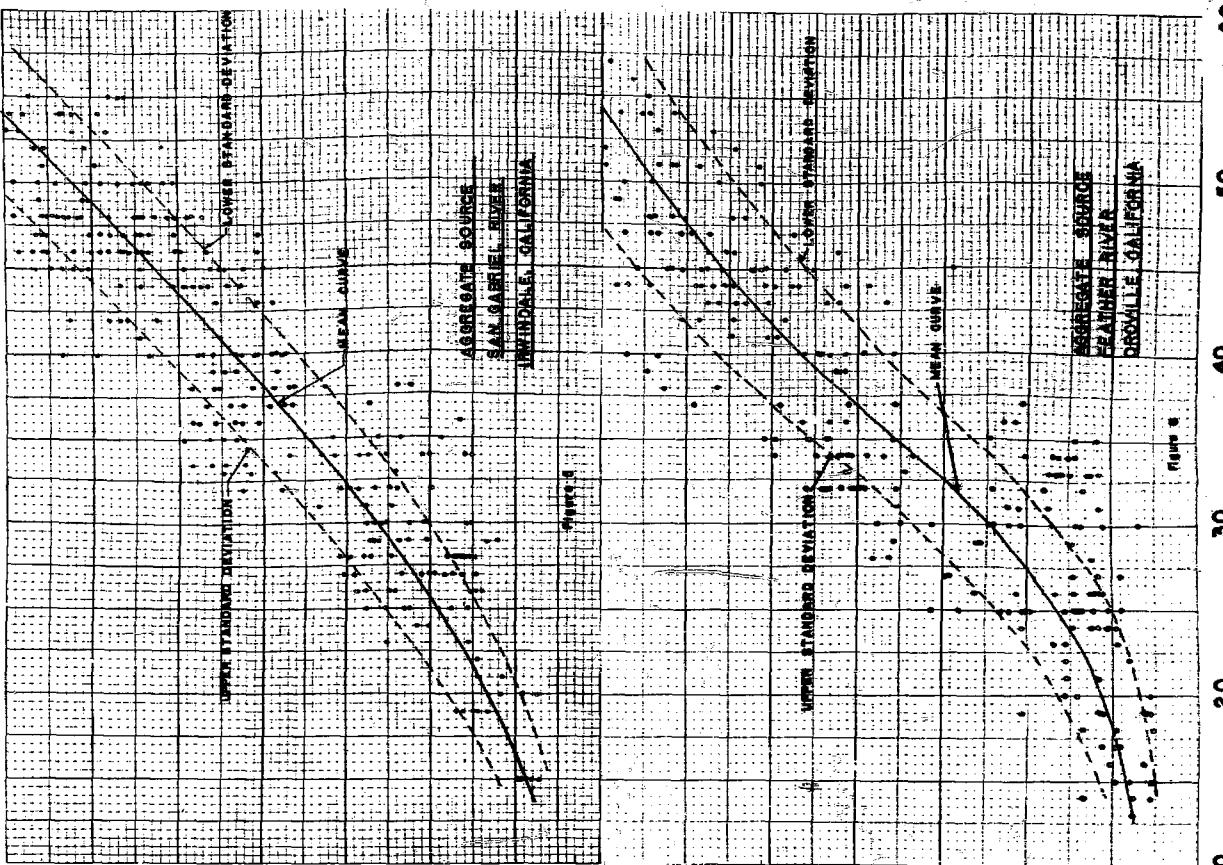


Half Section of Concrete
Test Hammer

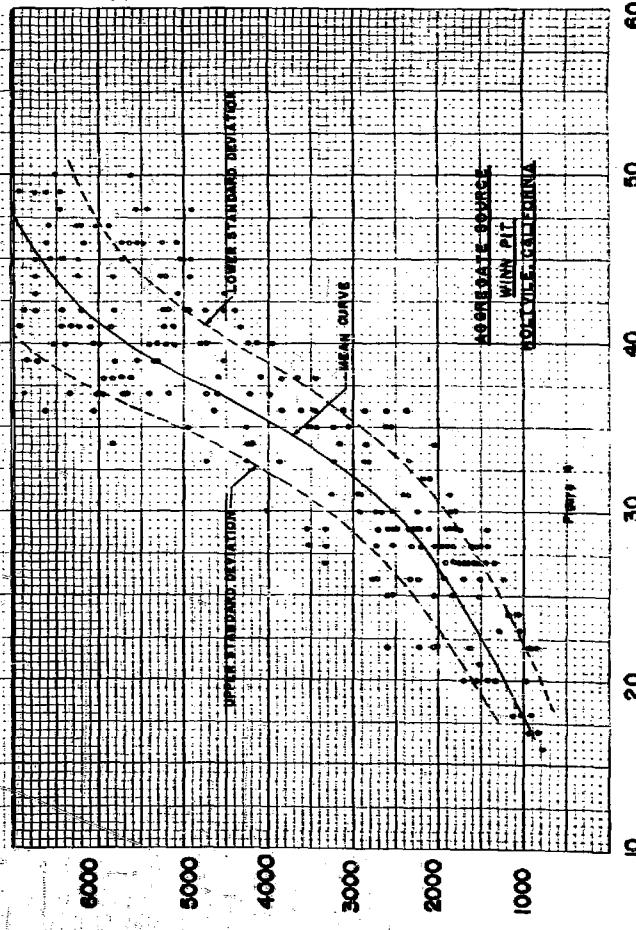
1. Hold the apparatus with one hand firmly so that the base rests solidly on the concrete surface to be tested.
2. With the free hand depress catch 3 into the slot.
3. Set pointer 5 to a reading about 10 scale units lower than the probable rebound as determined from a trial test.
4. With the free hand engage trigger 7 into the hammer and draw against the springs 6 to the fully extended position. Holding the apparatus steadily, carefully release trigger outwardly.
5. When released, the springs propel the hammer against the concrete and the impact causes the hammer to rebound. The catch 3 swings out and, on the hammer rebound the sliding pointer 5 is engaged, moving it to the end of the rebound stroke. The rebound number "R" indicated on the scale is then established.

Figure 2

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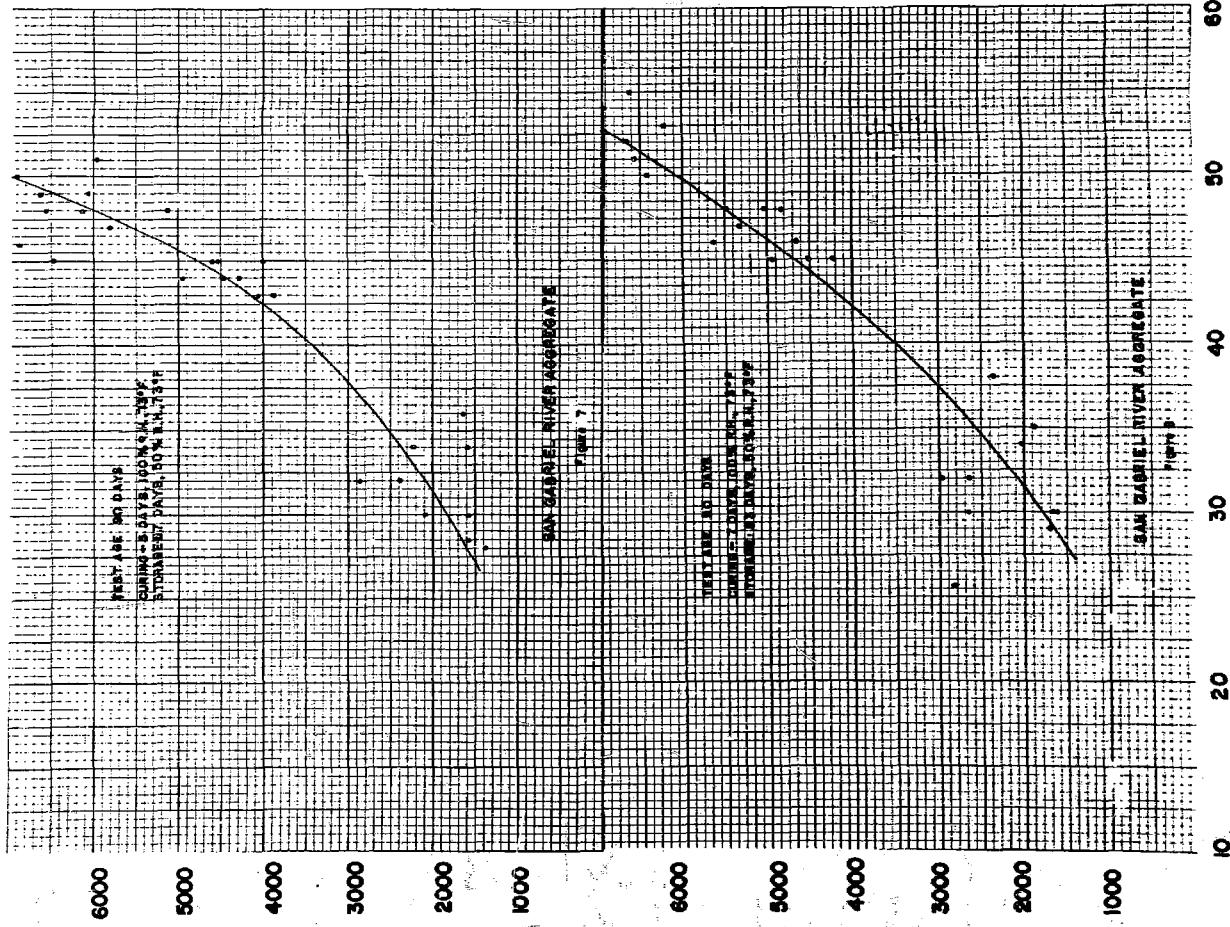
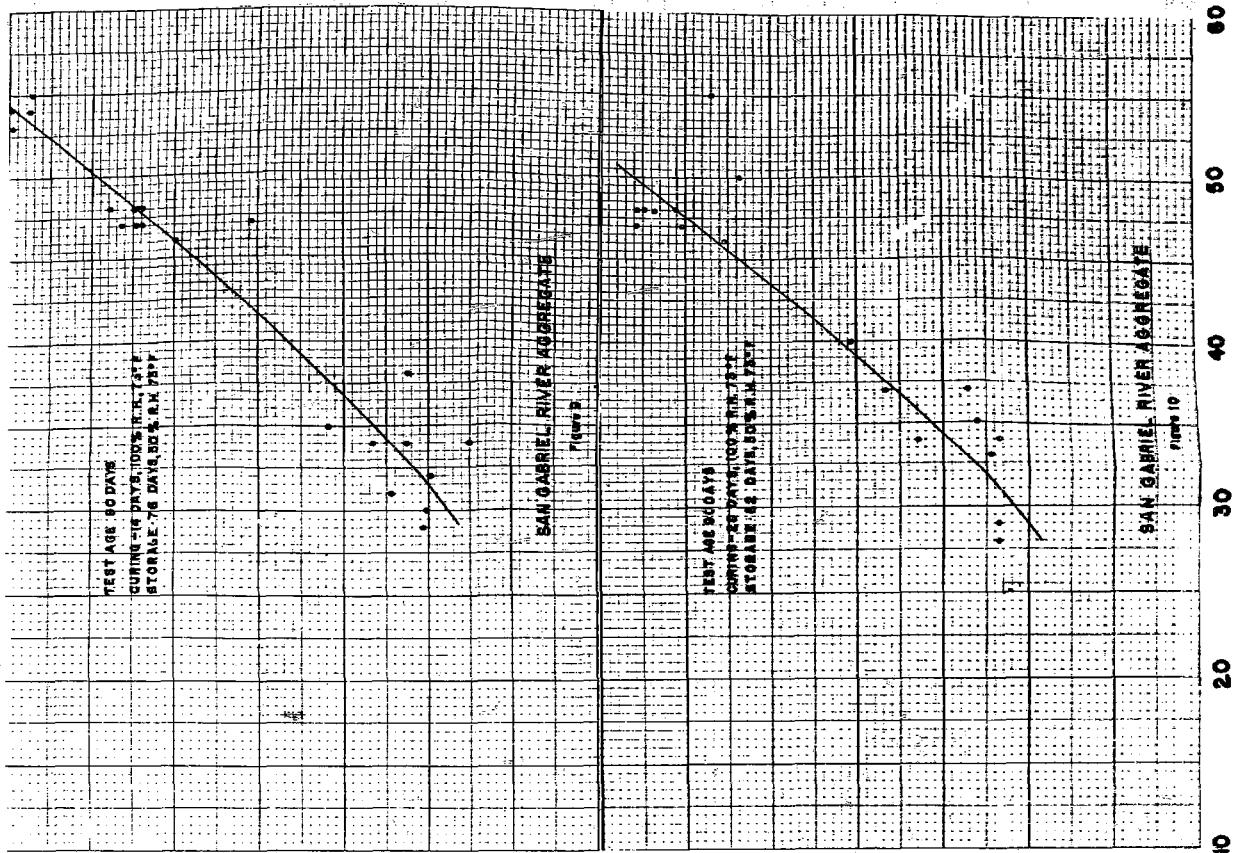


COMPRESSIVE STRENGTH P.S.I.



10 20 30 40 50 60 70 80 90

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6000

TEST ARE 7 DAYS
CURING-7 DAYS, 100% R.H., 72°F

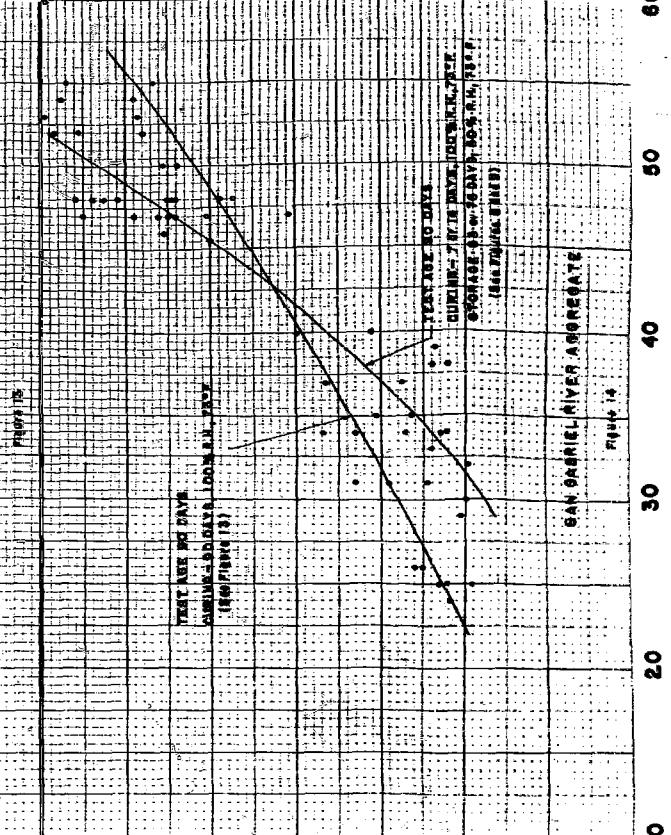
5000

TEST ARE 90 DAYS
CURING-70 DAYS, 100% R.H., 72°F

4000

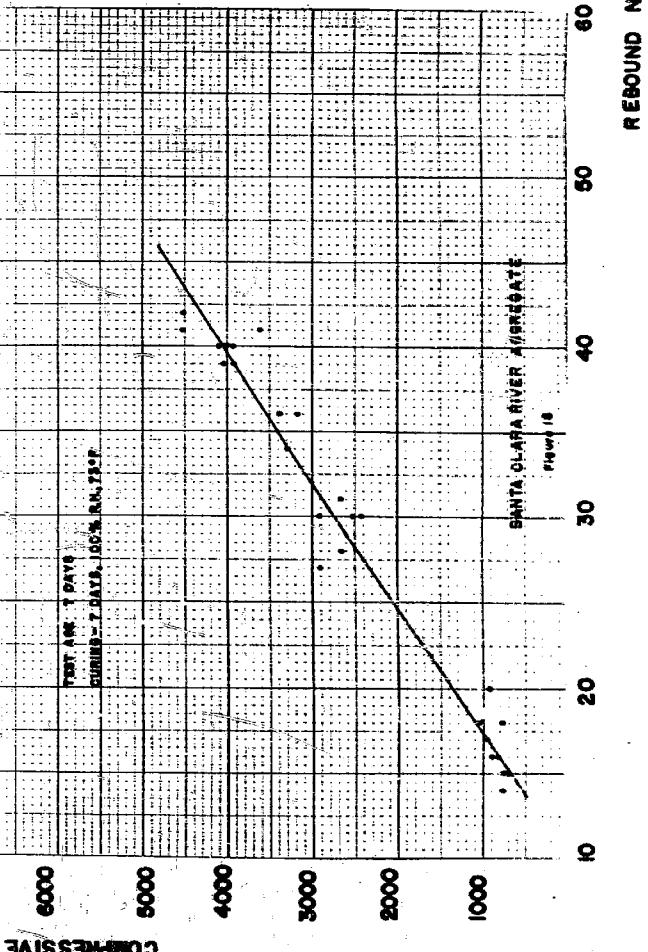
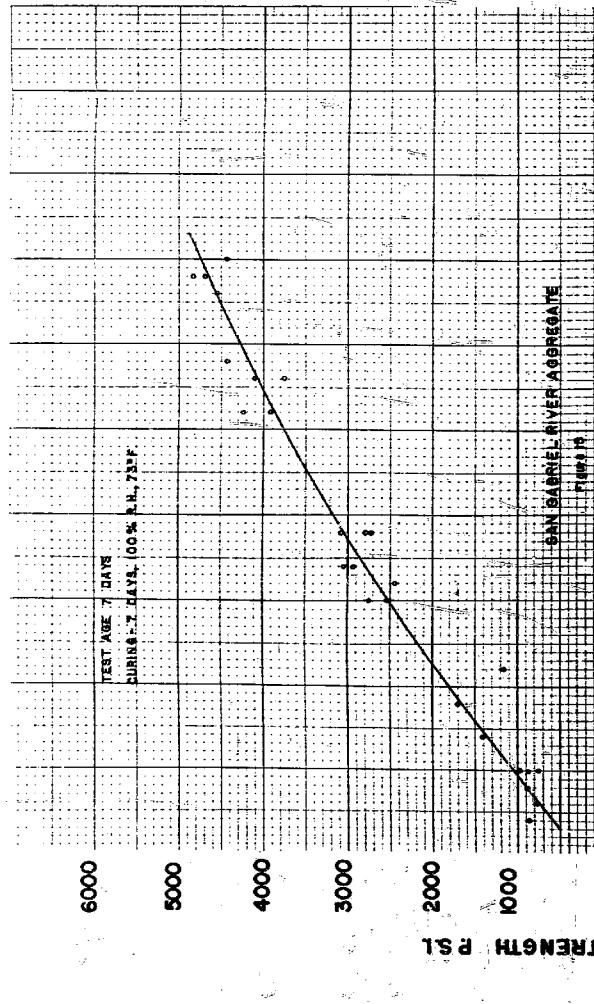
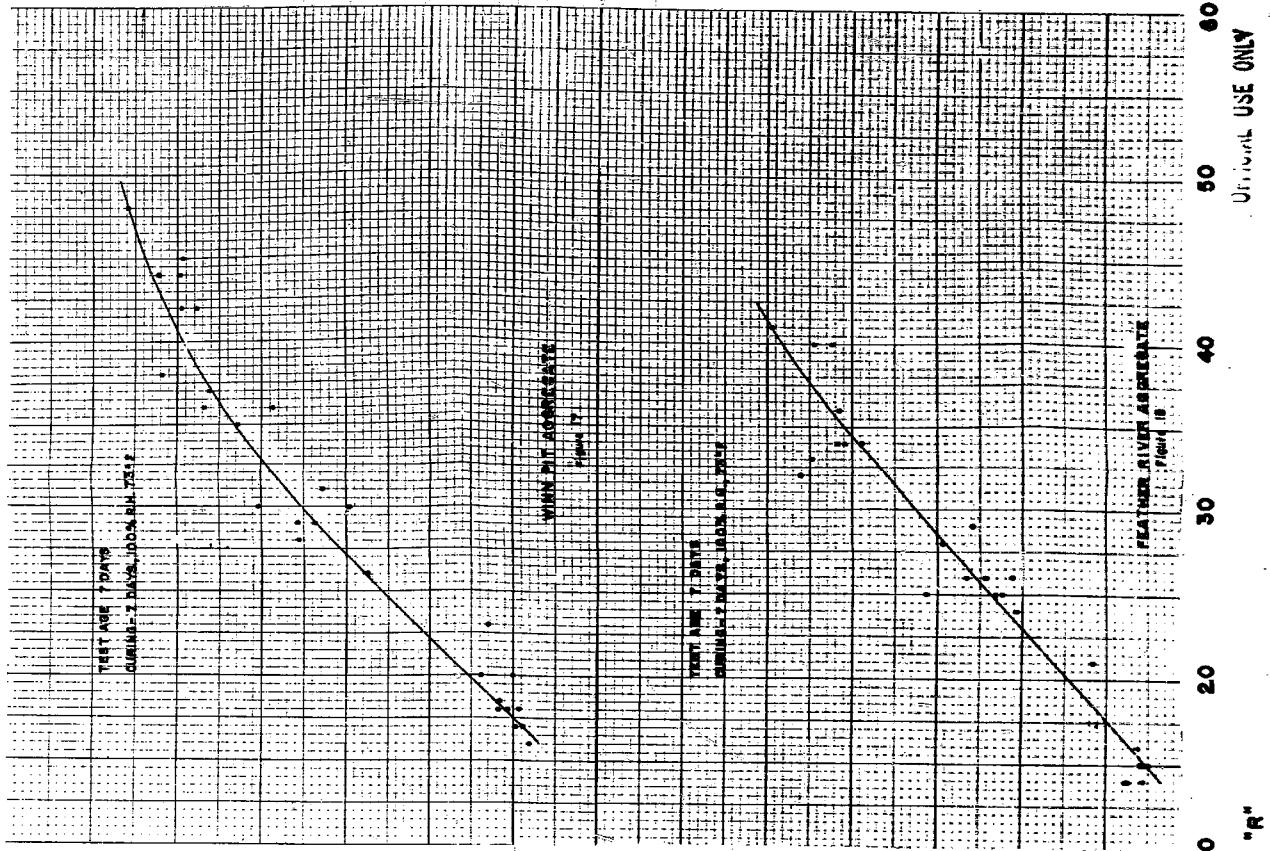
3000
2000
1000

COMPRESSIVE STRENGTH P.S.I.

SAN GABRIEL RIVER AGGREGATE
Figure 11SAN GABRIEL RIVER AGGREGATE
Figure 12

REBOUND NO. "R"

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